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硕 士 学 位 论 文

采用静电变形薄膜造型的自由曲面微透镜阵列研究

Research of Free-Form Micro Lens Array Molded by Electrostatic Force Deformed Template

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摘　要

自由曲面微透镜阵列可以用来实现光束整形、光场均匀化、太阳能电池的陷光结构，立体摄像及显示，光互连等很多功能，尤其是随着近年来光纤通信技术的快速发展和光纤入户的普及，与光纤光斑尺寸相仿的自由曲面微透镜的用途还在不断扩大。与之对应，现有的制造技术还难以实现低成本、直径在几十微米以下、可精确控制面型的微透镜阵列。例如通过金刚石钻头、激光加工等手段获得模具而复制获得的微镜头的尺寸一般在几百微米，而微喷打印，光敏胶热回流形成的微镜头的面型不能精确控制。

本文针对尺寸在几十微米以下的自由曲面微透镜阵列，提出一种称为“MEFDT”的制造方法，采用微细加工工艺制作了导电薄膜和驱动电极，利用静电力使导电薄膜变形，实现特定的曲面做为模具，再通过注模形成聚合物的微透镜阵列。这种方法和原有的微透镜阵列制作方法相比，可形成圆形、椭圆形、矩形、六边形等各种截面形状的微透镜阵列，并能通过改变电压和电极的位置，改变透镜的曲面轮廓，从而制造出各种形状、高填充比的自由曲面微透镜阵列。同时，这种变形薄膜形成的模具可以通过微细加工工艺大批量获得，有效降低了制造成本。

第二章阐述了采用“MEFDT”方法制备微透镜阵列的基本原理和流程。第三章建立起一套从多物理场仿真到形成特定光学曲面，再形成光学透镜实体模型，进而进行光学透镜仿真的完整设计方法。通过这个设计仿真流程，我们可以根据目标透镜的光学性能优化模具结构和电压。

第四章设计了工艺流程，采用SU-8光刻胶的微细加工工艺成功实现了单层电极静电变形薄膜模具的制作，并采用PDMS材料，用此模具制备了球形曲面，矩形球体曲面，六边形球体曲面，类花生壳形曲面等多种自由曲面的微透镜阵列。

第五章对获得的多种微透镜阵列进行了表征。包括用激光共聚焦显微镜测量了微透镜的轮廓，并与第三章的仿真结果进行对比，证明二者的误差在10%以内；用原子力显微镜测量了微透镜的表面光洁度，证明在1×1 μm2的范围内的表面粗糙度小\于2 nm；搭建光路检测了各种透镜的聚焦特性，并测量了焦距；以具有六边形边缘且边长为50 μm的微透镜阵列为例，通过对其静电变形薄膜模具施加150-300 V的

电压，发现获得的微透镜的焦距随电压增加从220微米减小到170微米。因此，有望通过调节电压使阵列内截面形状一致的微透镜获得不同的焦距，这种具有特殊光学性能的微透镜阵列在立体成像等领域具有应用价值。

综上所述，本论文研究了一种新的制造方法，以静电变形薄膜形成的曲面做为模具制作聚合物微透镜阵列。这种方法的优点包括：由于模具通过微细加工工艺制造，微透镜的尺寸可以缩小至几微米，可以光刻出任意的截面形状；做为模具的薄膜通过溅射工艺获得，表面粗糙度一般小于几纳米，获得的微透镜的表面光洁度较高；通过电压可以控制薄膜的变形，从而控制微透镜的轮廓和光学性能，能够实现不同焦距的微透镜组成的阵列以实现特殊的光学性能。

关键词：微透镜阵列;静电变形薄膜;自由曲面

Abstract

Micro lens array (MLA) was broadly used in optical system for beam homogenization beam shaping, photonic interconnection, flat panel display, compound-eyes image recording and solar concentration, etc. Especially MLAs that matches the core size of optic fiber are in active demand due to the rapid expansion of optical communication and fiber to the house. However, low cost, micro sized MLAs with well-controlled profile are still difficult to be fabricated. For example, the size of micro lenses that duplicated using mold prepared by diamond micro milling or excimer laser machining is usually more than a hundred micron. Meanwhile, the surface profile of polymer micro lenses fabricated by reflowing patterned photosensitive or micro ink-jet printing is normally out of control.

In the dissertation, a so-called Molding by Electrostatic Force Deformed Template (MEFDT) method was proposed to replicate shape-controllable MLAs utilizing an electrostatic force deformed membrane as a template, and the conductive membrane and its underneath electrodes were prepared by micro fabrication technology. Comparing with those reported MLA fabrication methods in the literature, MLA with various of contour such as circular, square, rectangle, hexagon, peanut shell shape, and so on can be fabricated using “MEFDT” methods, and the curvature of the MLAs is reconfigurable by applying different voltages on the mold. Therefore, freeform MLAs can be realized using this method. In addition, the mold can be prepared in a large batch by micro fabrication, which reduced the cost of the MLAs effectively.

The principle and process flow of the “MEFDT” method were introduce briefly in chapter 2. An integrated simulation environment from the configuration of the template to the final optical performance of the micro lens array was presented in chapter 3. First, the electric field distribution at certain of applied voltage was

figured out by electromagnetic field simulation. Next, the electromagnetic field distribution was input into a finite element analysis environment to obtain the electrostatic force on the template, and then a deformed surface was derived. The output scattering points on the deformed surface were treated mathematically to generate a three dimensional body surrounded by the deformed surface and a flat surface, This body was arrayed to form a micro-optics component, which was input into an optical simulation environment to get its optical performance. Using this simulation procedure, the process parameters and applied voltage can be determined for preparing a MLA with required optical performance.

The fabrication of the MLAs was discussed in chapter 4. A SU-8 cavity, a conductive membrane on the top surface of the cavity and electrode on the bottom were prepared by micro fabrication technology to act as the template. Polydimethyl-siloxane was poured on the template that deformed by applied voltage, curing and peeled off to realize MLAs. In this dissertation, various of MLAs with different contour such as circular, square, rectangle, hexagon and peanut shell-shape were fabricated successfully.

The fabricated MLAs was characterized in chapter 5. The profile of the MLAs was measured by a three dimensional laser measuring microscope (OLS1200-FAR2, Olympus), and a deviation about 10% was found between the simulated and measured profile. An atomic force microscope (AFM, SPA-400, SEIKO, Japan) was used to measure the surface roughness of a prepared spherical PDMS MLA, the root mean square roughness, RMS was measured to be about 2 nm in a 1.0×1.0 μm 2area. The focal length of the fabricated MLA was optically examined, and the fabricated MLA showed adjustable focusing by applying different voltages on their template in molding process. For example, the focal length of hexagonal MLAs with the side length of 50 μm was found to decrease from 220 to 170 μm while the template voltages increased from 150 to 300 volt. This phenomenon hints that a MLA with micro lenses with different focal length can be produced

using "MEFDT" method, which is promising for some applications like three dimensional image recording.
In conclusion, A method called Molding by Electrostatic Force Deformed Template (MEFDT) was used to realize shape-controllable micro sized polymeric MLAs in this dissertation. Through adjusting the contour of the template, position of the electrodes and the applied voltage, various of micro sized, freeform MLAs with defined geometry were prepared. Comparing with other reported approaches, MEFDT method is supposed to provide more flexibility on the geometrical design of MLA, higher accuracy on shape control and lower cost on fabrication.

Keywords: Micro lens array; electrostatic deformed template; freeform

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